Efficient Broadcast on Computational Grids

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Overview

- MPI programs can contain point-to-point and collective communication operations
- Collective communication operations (broadcast, scatter, gather) are potential performance bottlenecks for scientific computing codes
- Efficient broadcast is needed for wide area and grid computing that uses collective communication
  - The penalty of inefficient global communication is higher on wide area networks than on clusters and local area networks

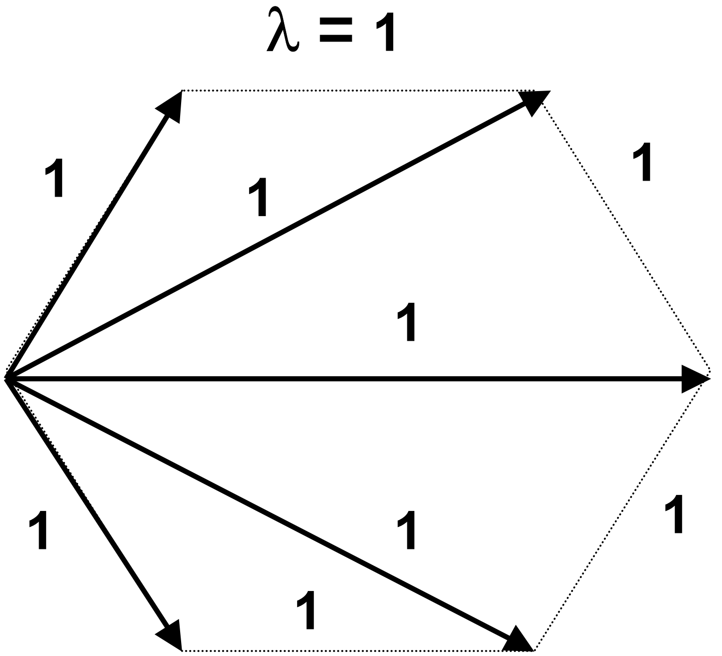
Problem Formulation

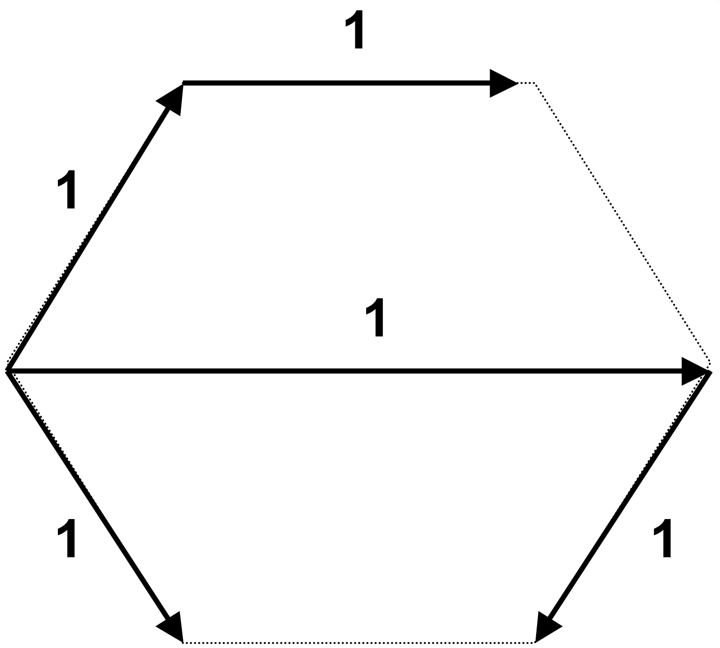
- Set of networked computer resources represented as a strongly connected graph G = (V,E)
  - Vertices represent computer nodes
  - Edges represent the interconnect
  - Each edge (u,v) in E has a weight w(u,v): the latency of communication between u to v
- A message is sent from a designated root to all processes such that:
  - For each edge (u,v), it takes time $\Delta(u,v)$ to inject the message at u for delivery to v
  - The sender can inject only one message at a time
- Goal: find a broadcast schedule: set of point-to-point communication operations performed in a certain order

Approaches

- Flat-tree: roots sends directly to all processes
- Binomial tree (MPICH)
- Multi-level tree with each level representing a different type of communication (MPICH-G2):
  - Top level is slowest (wide area networking)
  - Bottom level is fastest (parallel machine/cluster)
  - Does not prescribe how to do broadcast within a level
  - A level can include a large number of nodes, e.g., machines at various campuses
- Single-source shortest path combined with a labeling algorithm to find the schedule

Single Source Shortest Path

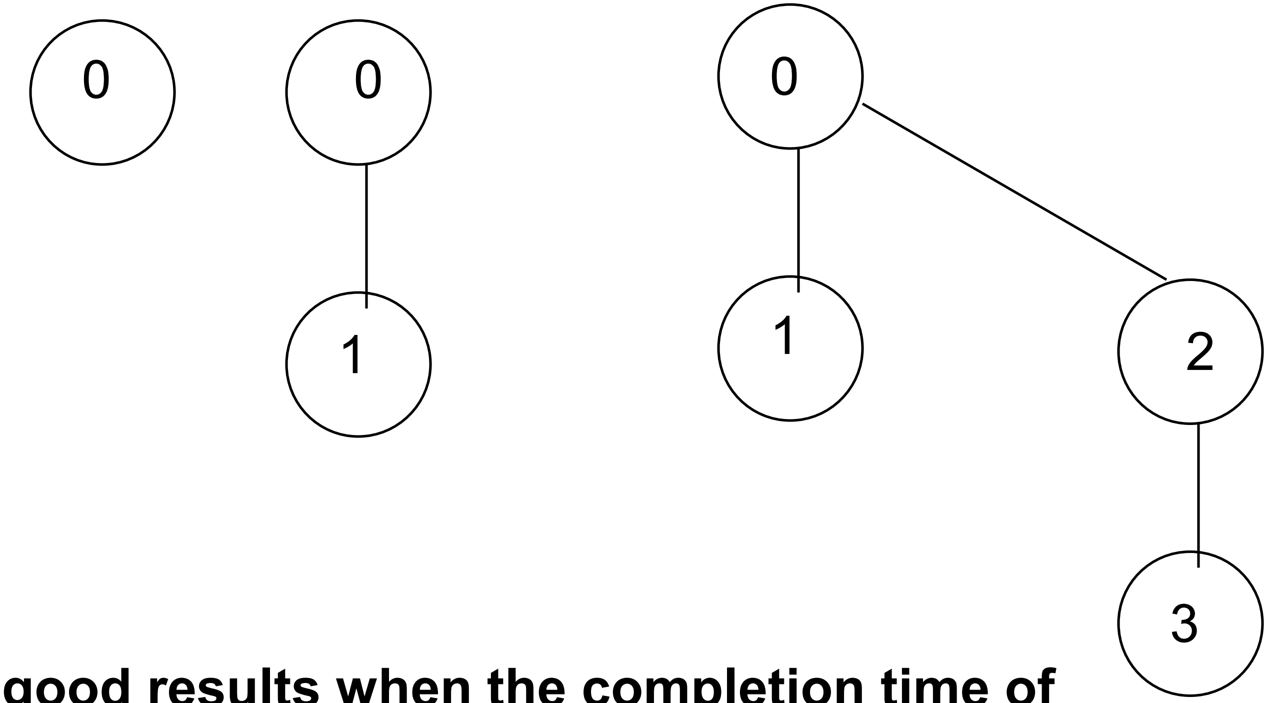




Single Source Shortest Path is not optimal for broadcast: **1 + 5** Δ

Broadcast schedule with time **2 + 3** Δ, better for Δ > 0.5.

Binomial Tree (used by MPICH)



Gives good results when the completion time of a send is close to the completion time of the matching receive.

By contrast, flat tree is good when the completion time of a send is much smaller than that of the receive

Proposed Method

- Find a tree T that represents the communication topology
    - vertex (machine) receives the message from the parent vertex
    - single-source shortest path combined with a labeling algorithm to find the schedule
    - extend single source shortest path to incorporate the effect of the injection time
- Determine the order of sending the messages along the edges of the tree, in terms of a vertex labeling

Extended single source shortest path

- Communication tree: extend Dijkstra's single-source shortest path to account for the injection time
- When updating the distance to v,
  - change the distance comparison from

$$dist[v] > dist[u] + w(u,v)$$

to

$$dist[v] > dist[u] + w(u,v) + \Delta(u,v)$$

  - If dist[v] is updated, increase d[u] with the injection time

$$dist[u] = dist[u] + \Delta(u,v)$$

Extended single source shortest path 2

```
dist[0:V-1] = infinity ; // V = number of vertices
dist[root] = 0;              // dist = length of path from root
parent[root] = NULL;  // parent defines the E-SSSP tree
queue = init_queue(G, dist); // priority queue by dist
while ( ( u =  dequeue_min(queue) ) )  {
   // shortest distance from u to all neighbors in queue
   while ( (v = get_next_neighbor(G, u)) ) {
     if(v $\in$ queue && dist[v] > dist[u] + w(u,v) + $\Delta$(u,v) ) {
```

Extended single source shortest path 3

```
      // new min for dist[v]
      dist[v] = dist[u] + w(u,v) + Δ(u,v);
      decrease_key( queue, v, dist[v] );
      // add the injection time to dist[u]
      dist[u] = dist[u]  + Δ(u,v);
      increase_key( queue, u, dist[u] );
      parent[v] = u; // update E-SSSP tree
     } // endif
   }  // end get_next_neighbor
} // end  dequeue_min
```

Vertex Labeling

- Label the vertices: the label of a vertex u is the time it takes for the messages sent from u to reach all the vertices in the subtree rooted at u
- Label vertices recursively

Label(u) = 0, if u is a leaf

max{ label(v_i) + w(u, v_i) + i Δ(u, v_i), v $\in$ E }

u is not a leaf

where the vertices v_i are arranged such that

label(v_1) + w(u, v_1) $\geq$ label(v_2) + w(u, v_2) $\geq$ …

- The label of u is the smallest label given the labels of the children

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Labeling algorithm 1

```
label_nodes( T, V, E, w, u, label) {
  // T is the E-SSSP tree
  label[u] = 0;
  if ( u is a leaf in T )  return;
  children = adjacency_list(T, u);
   // recursion
   while ( v = get_next_vertex(children) ) {
     label_nodes( T, V, E, w, v, label);
   }
```

Labeling algorithm 2

```
// sort by decreasing label(v_i) + w(u, vi)
sort_decreasing_label(children, label, w);
count = 1;
// find label[u];
label[u] = 0;
while ( v = get_next_vertex(children) ) {
  if ( label[u] < label[v] + w(u,v) + count*Δ(u,v)  ) {
     label[u] = label[v] + w(u,v) + count*Δ(u,v) ;
  }
  count++;
}
```

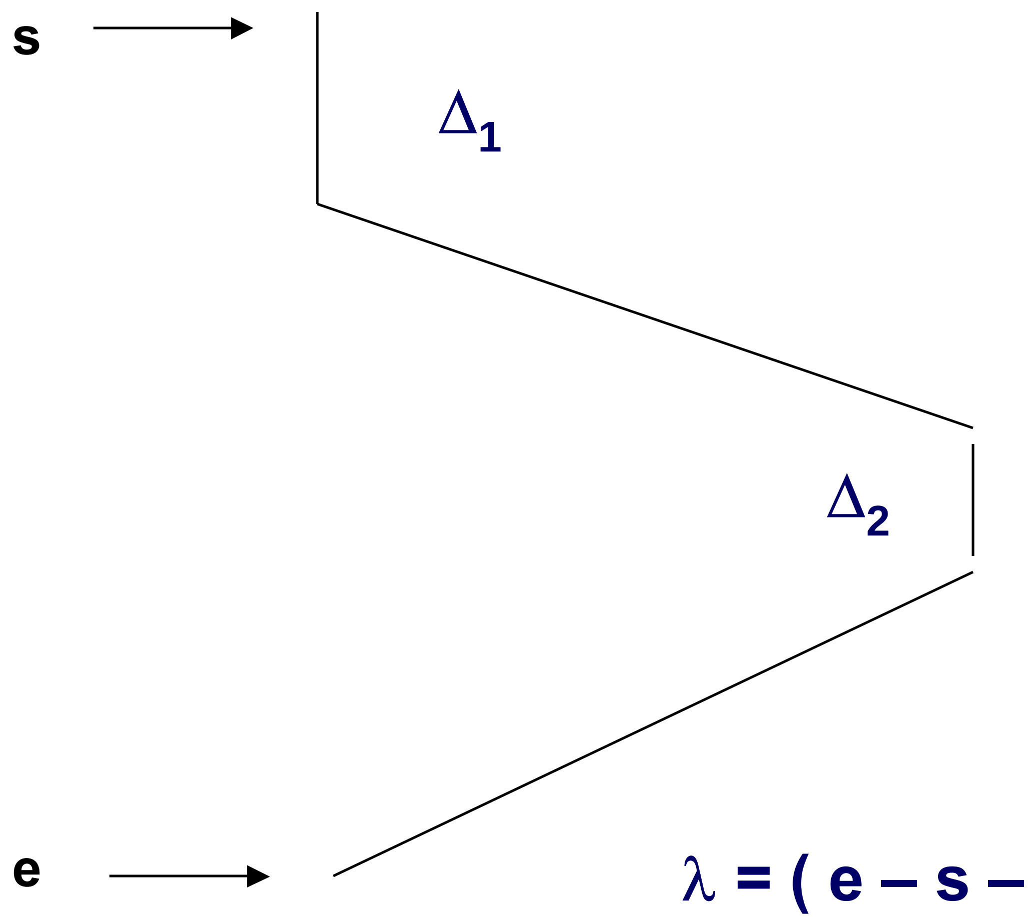
Implementation of Broadcast 1

```
extended_single_source_shortest_path();
label_nodes( );   // children sorted by decreasing label
src = get_parent() ;
clist = get_children() ;
if (src != NULL) {
  MPI_Recv( src );
}
foreach dest in clist {
 MPI_Send( dest );
}
```

Implementation of Broadcast 2

- MPI_Send() rather than MPI_Isend ()
- Safe use of MPI_Isend requires, in addition to invoking either MPI_Waitall or MPI_test, some form of handshaking between sender and receiver, e.g., receiver sends a “ready to receive” message
  - MPI_Isend uses message buffers and the handshake makes sure that the buffers are not overrun
  - But handshake introduces additional synchronization overhead

Measuring the latency



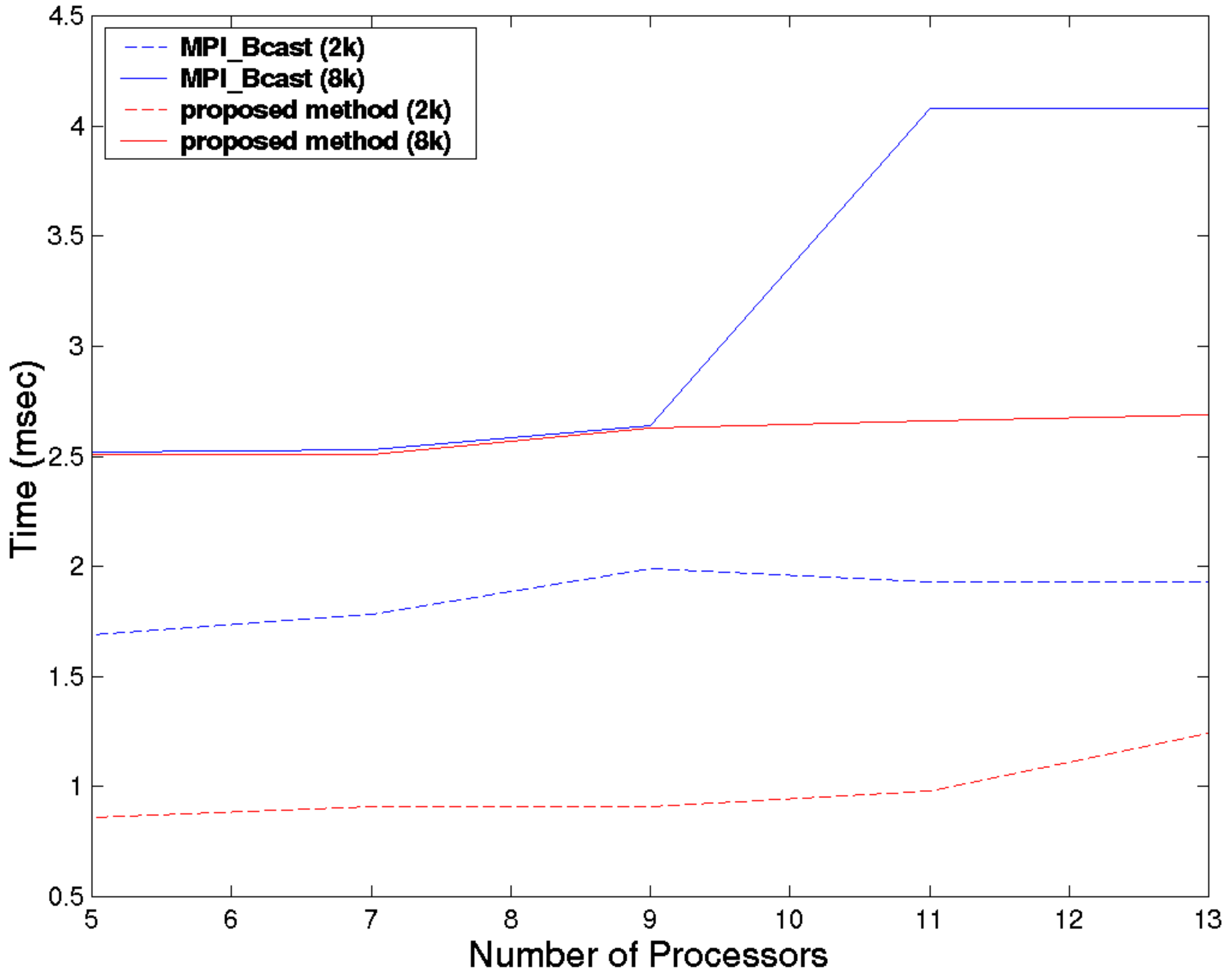
$$\lambda = (e - s - (\Delta_1 + \Delta_2)) / 2$$

Testbed

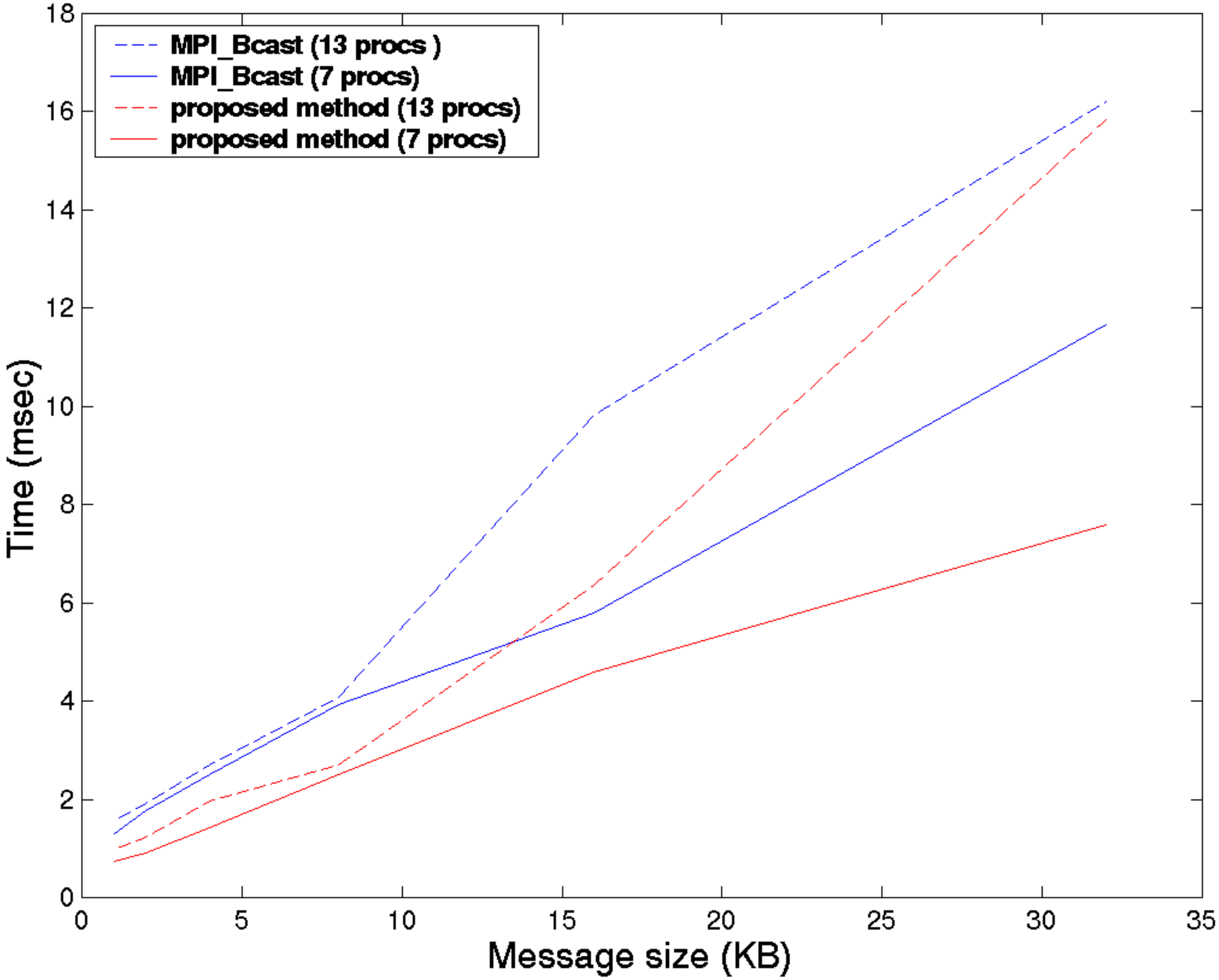
- Eight machines (Pentium II, III, and 4) located at two NRC campuses in Ottawa (about 6 miles apart)
- Injection times and latencies between nodes span a significant interval

λ = 0.085 .. 1.2 ms
Δ = 0.035 ... 0.3 ms

Broadcast time vs Number of processors



Broadcast time vs Message Size



Conclusions

- Proposed method outperforms MPICH for small and moderate message sizes
- For large message sizes, the injection time includes the effect of bandwidth if MPI_Send is used for point-to-point communication, and the model becomes inaccurate
- Future work
  - replace MPI_Send with MPI_Isend, to improve performance and model accuracy
  - Include the bandwidth in the model